Measurement of Directed Flow via three particle azimuthal correlations at RHIC-PHENIX

Hiroshi Masui

For the PHENIX Collaboration

JPS meeting

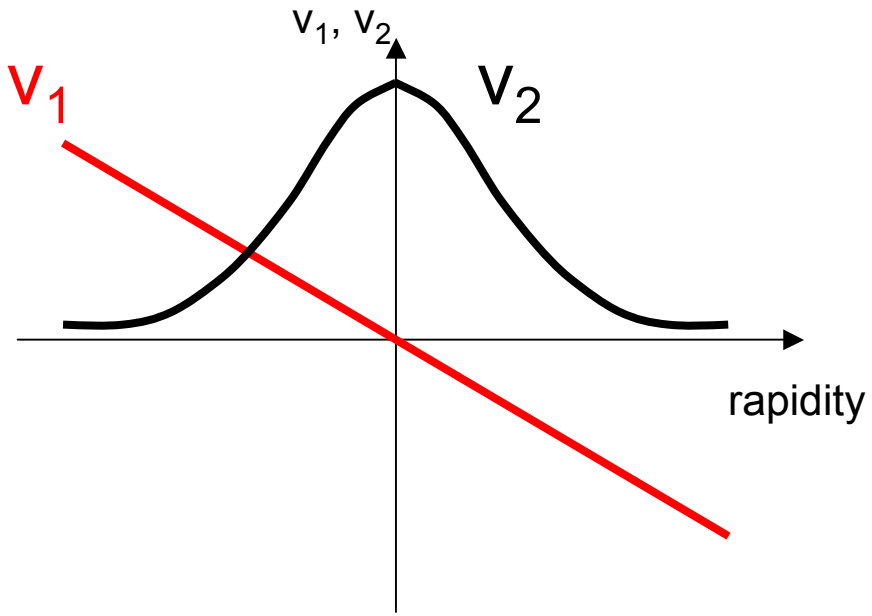
Outline

- Azimuthal anisotropy
- Theoretical prediction of Directed Flow
- PHENIX experiment
- Analysis method
- Results
- Summary and Outlook

Azimuthal anisotropy
Directed/Elliptic Flow

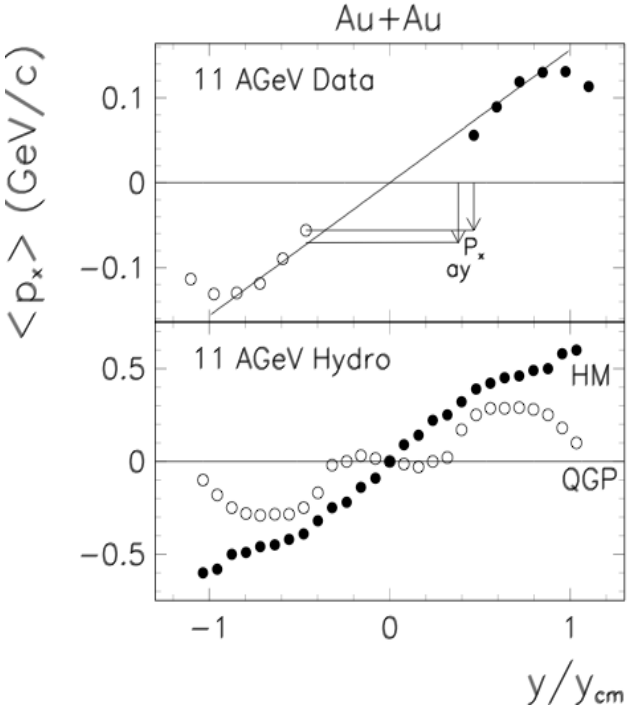
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos[n(\phi-\Psi)]\right)$$

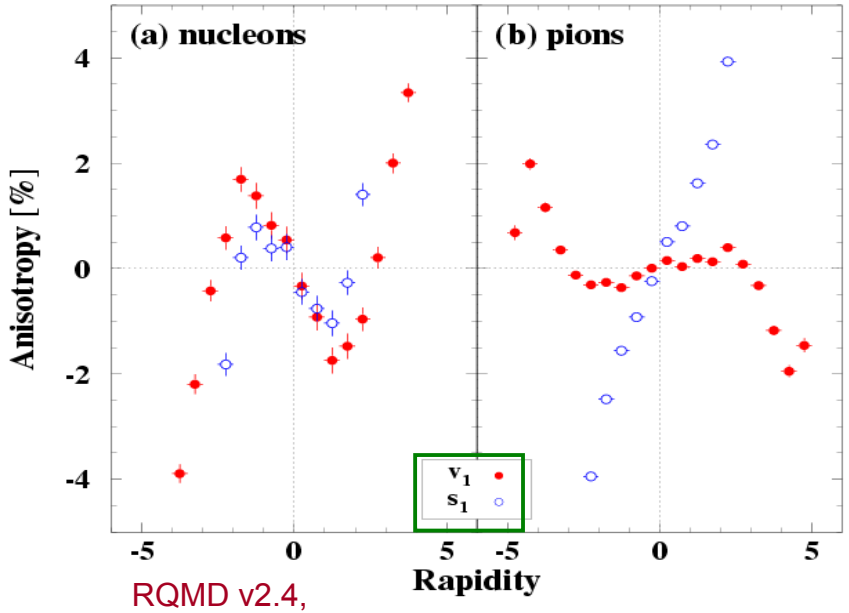
v_n (n=1,2): strength of directed/elliptic flow
ϕ : azimuthal angle of detected particles
ψ : azimuthal angle of reaction plane



- Anisotropic Flow
  - Directed/Elliptic Flow
  - Sensitive to the system evolution at early time and the equation of state.
  - Might be used to search for new state of matter (QGP) and phase transition.

Theoretical prediction of Directed Flow (v_1)





RQMD v2.4,
√s = 200 GeV Au + Au collisions
b = 5 – 10 fm

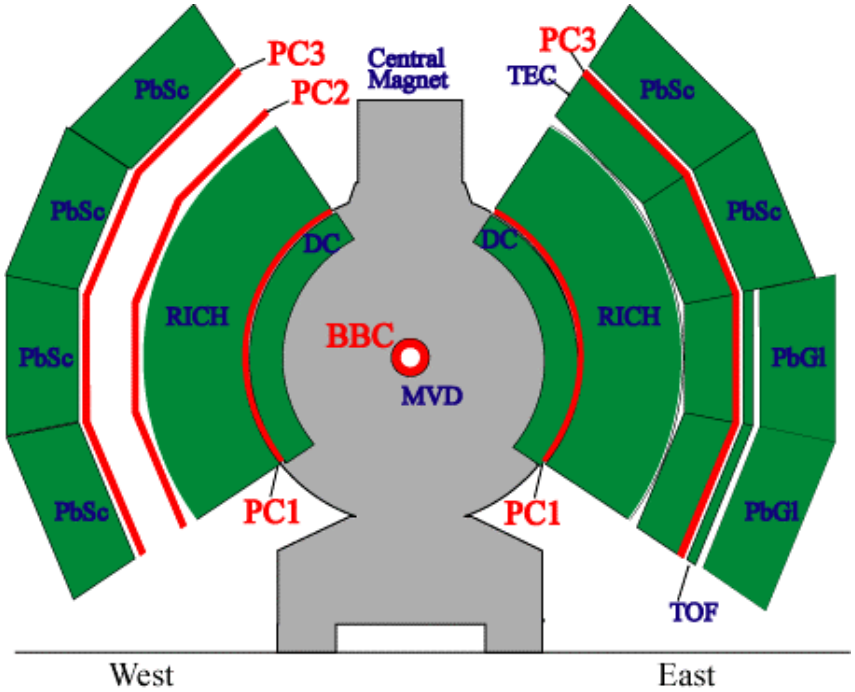
- Anti-flow/3rd flow component, with QGP
  - v_1 flat at mid-rapidity.

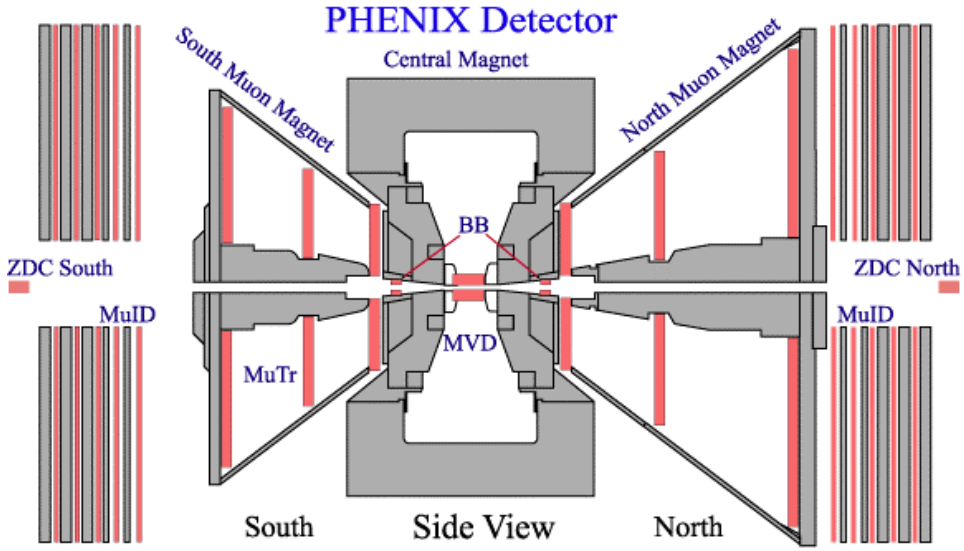
Brachmann, Soff, Dumitru, Stocker, Maruhn, Greiner Bravina, Rischke , PRC 61 (2000) 024909. L.P. Csernai, D. Roehrich PLB 458, 454 (1999) M.Bleicher and H.Stocker, PLB 526,309(2002)

- v_1 wiggle, no QGP necessary
  - Baryon stopping
  - Positive space-momentum correlation

R.Snellings, H.Sorge, S.Voloshin, F.Wang, N. Xu, PRL (84) 2803(2000)

Experimental Setup PHENIX Detector





- Minimum Bias Trigger
  - BBC (Beam Beam Counter)
- Collision Vertex
  - BBC
- Centrality
  - BBC, ZDC (Zero Degree Calorimeter)
- Reaction Plane
  - BBC, DC (Drift Chamber), PC (Pad Chamber)
- Tracking / Momentum
  - DC, PC

Analysis method

- Reaction Plane method $v_1\{RP_1\}$, $v_2\{RP_2\}$

$$\left\langle e^{in(\phi-\Psi)} \right\rangle = v_n$$

- Two particle + Reaction Plane $v_1\{RP_2\}$

$$\left\langle e^{i(\phi_a+\phi_b-2\Psi_2)} \right\rangle = v_1^a v_1^b \left\langle \cos[2(\Psi_{true}-\Psi_2)] \right\rangle$$

- Three particle correlation $v_1\{3\}$

$$\left\langle e^{i(\phi_a+\phi_b-2\phi_c)} \right\rangle = v_1^a v_1^b v_2^c$$

Central arm

BBC

Basic fomula of three particle correlation method
N. Borghini, P.M. Dihn, J-Y. Ollitrault, PRC 014905 (2002)

Non-flow contribution

$$\left\langle \cos(\phi_a - \psi_2)\cos(\phi_b - \psi_2) - \sin(\phi_a - \psi_2)\sin(\phi_b - \psi_2) \right\rangle \approx v_{1a} v_{1b} v_2$$

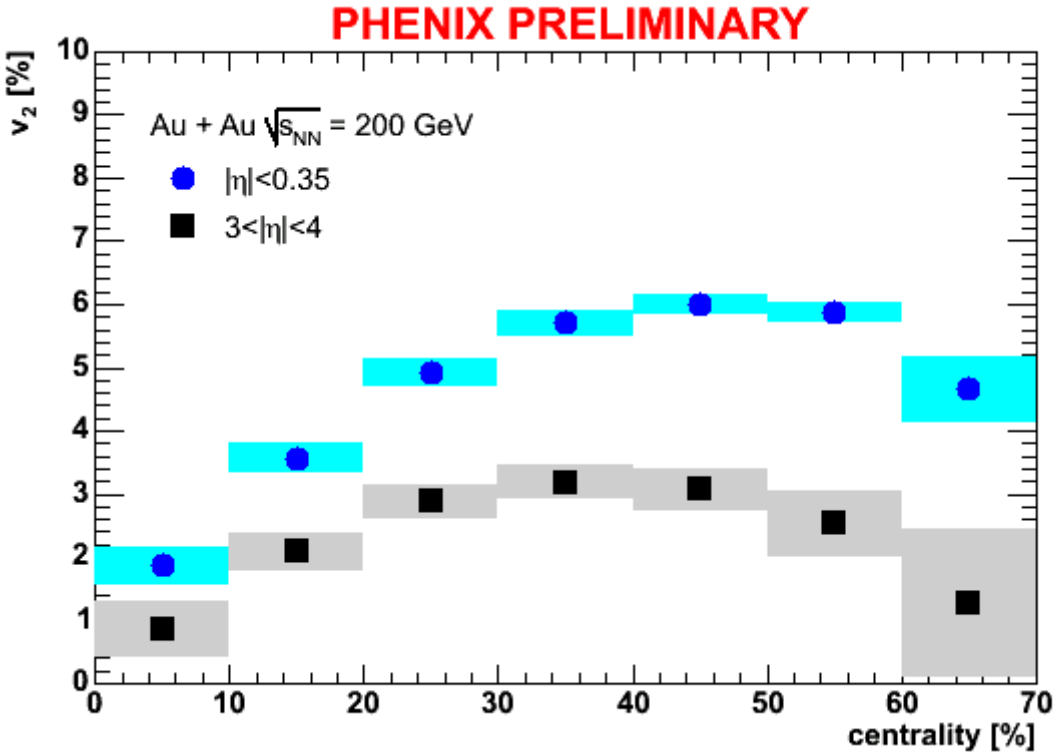
In-plane component
Flow + Non-flow

Out-of-plane component
Non-flow

- Three particle correlation (or two particle + reaction plane) is less sensitive to non-flow contribution than reaction plane method.
- Takes advantage of the knowledge about the reaction plane derived from the large elliptic flow
  - minimizes non-flow effect.
- Can measure the sign of v_2.

Elliptic Flow $v_2\{RP_2\}$

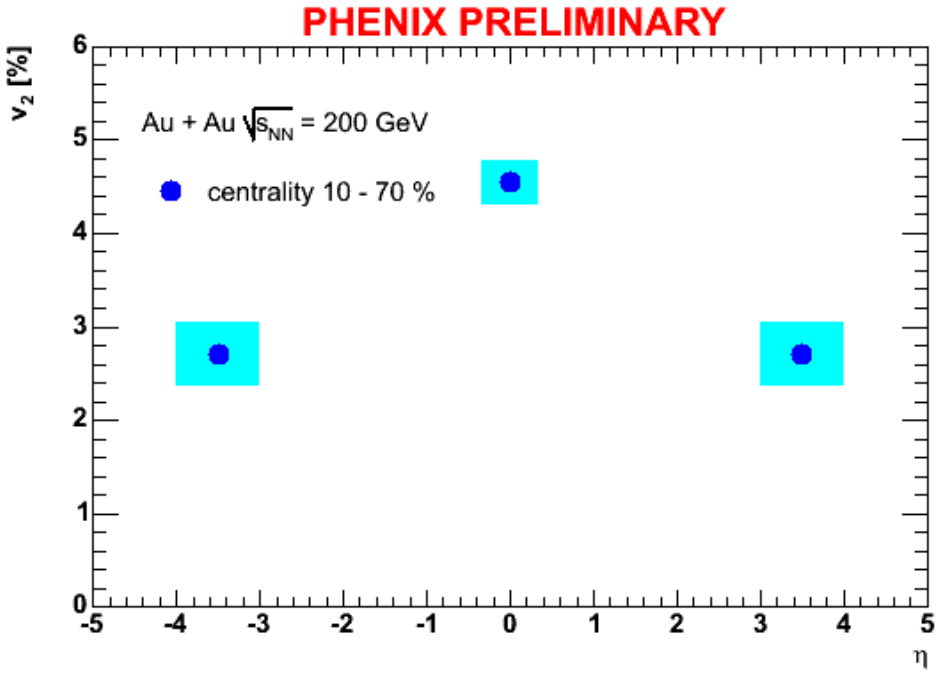
Comparison of Mid-rapidity ($|\eta|<0.35$) and Forward rapidity ($3<|\eta|<4$)

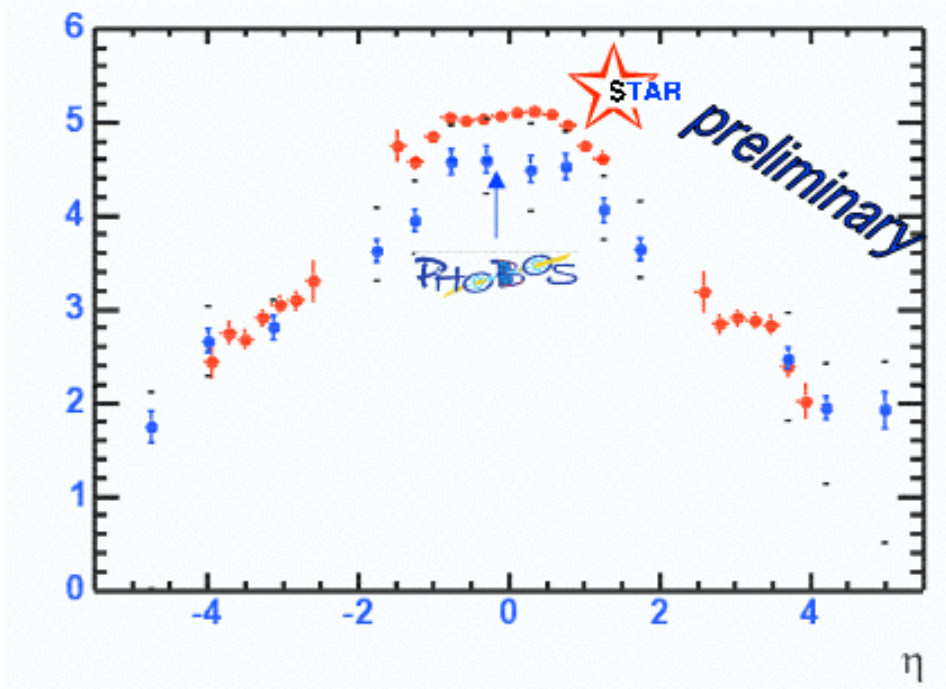


- Elliptic Flow measurement has been done by the standard reaction plane method @ mid-rapidity and forward rapidity.
- Used as input for 3 particle correlation method.

Elliptic Flow

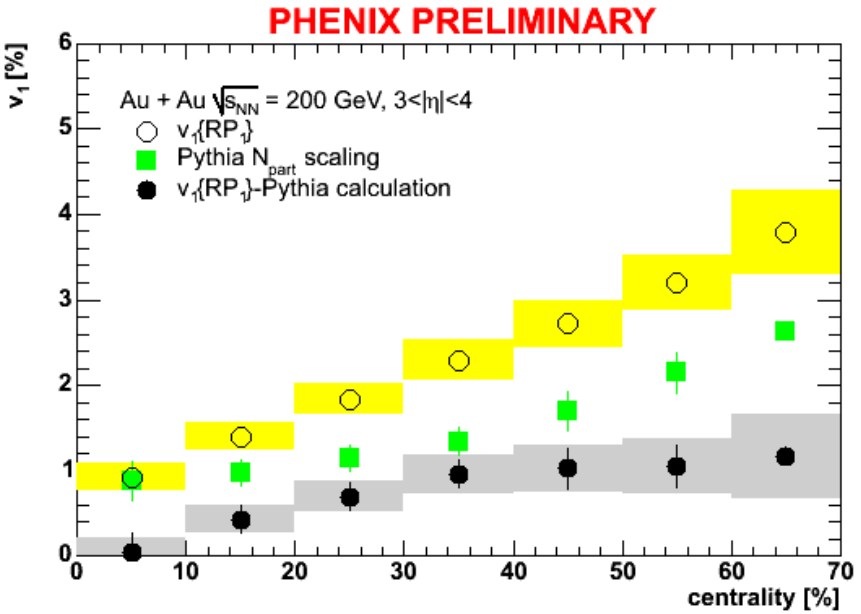
Comparison of PHENIX to other experiments

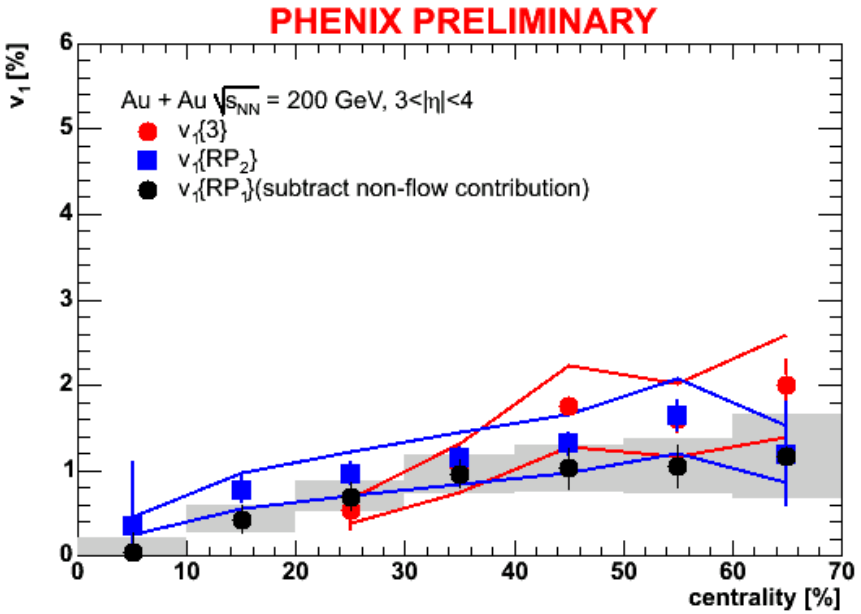




- PHENIX v_2 is consistent with PHOBOS and STAR results.

Directed Flow (3<|η|<4)

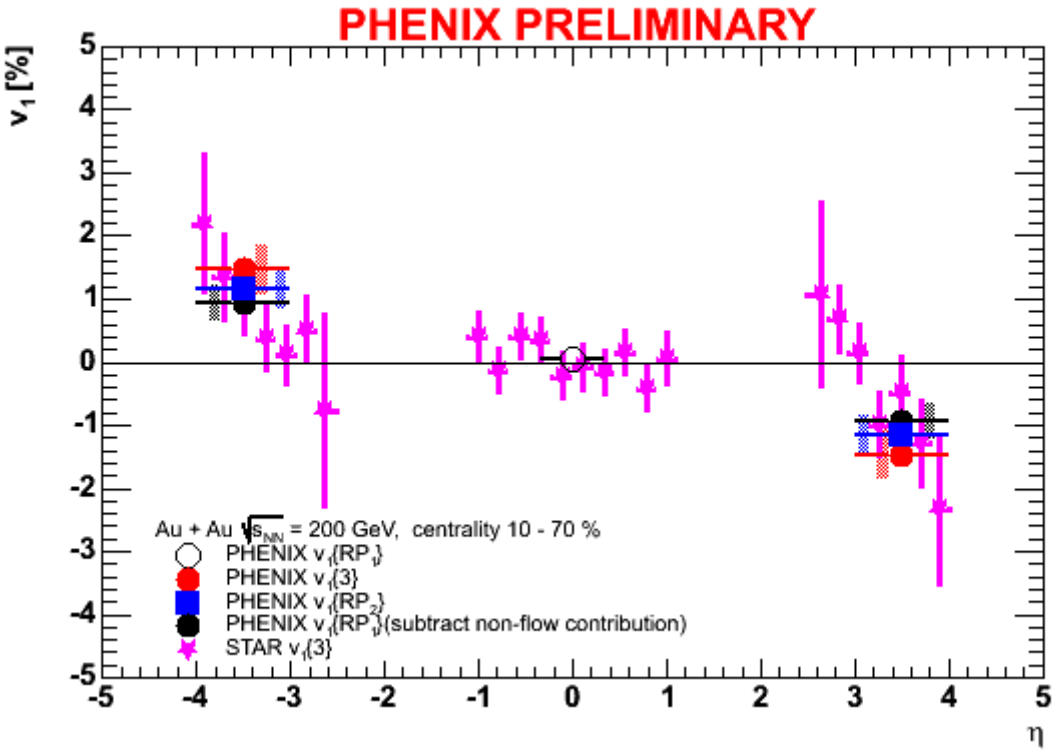




- ○ Flow + Non-flow ($v_1\{RP_1\}$)
- ■ Non-flow
- ● Flow
- ● $v_1\{3\}$
- ■ $v_1\{RP_2\}$

- Comparison of 3 independent analysis.
  - $v_1\{RP_1\}$ subtracted non-flow contribution.
  - $v_1\{RP_2\}$
  - $v_1\{3\}$
- Very good agreement within the error bars.

Directed Flow
Comparison of PHENIX and STAR



- Integrated Directed Flow in 10 – 70 % centrality bins.
  - Sign of v_1 is defined by hand.
  - Systematic errors are shown by color bands.
- Comparison of PHENIX results to STAR $v_1\{3\}$.
  - All of the PHENIX results are consistent with STAR $v_1\{3\}$.

Summary

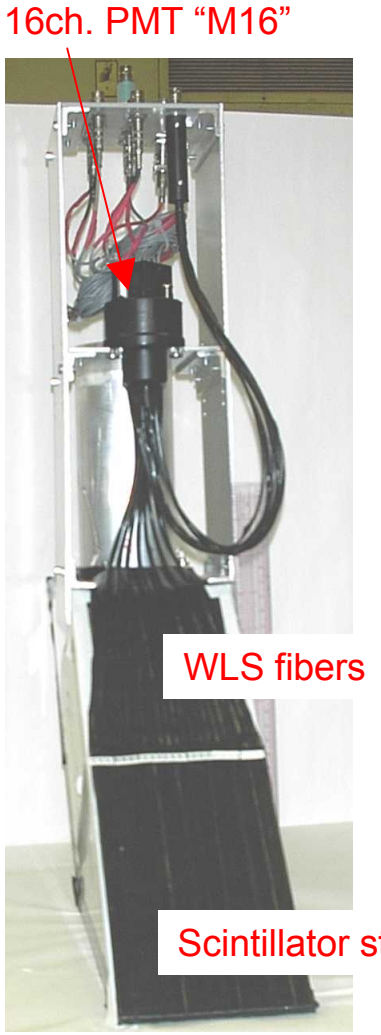
Elliptic Flow

- First measurement of Elliptic Flow (v_2) in Forward rapidity ($3<|\eta|<4$) @ PHENIX.
  - Consistent with PHOBOS and STAR.

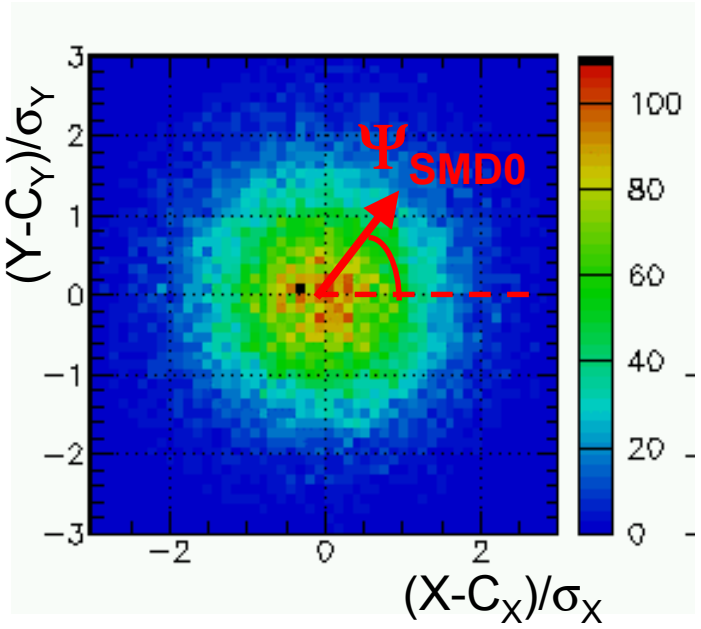
Directed Flow

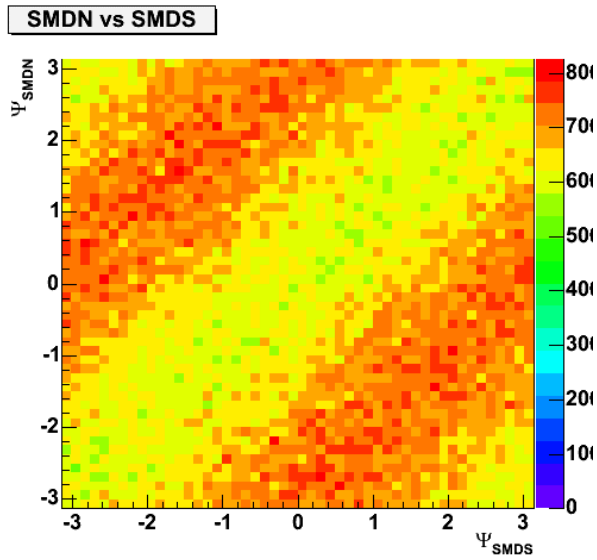
- First measurement of Directed Flow (v_1) @ PHENIX.
- $v_1\{RP_2\}$ and $v_1\{3\}$ are less sensitive to non-flow contribution than v_1 from the standard reaction plane method.
- The results of v_1 @ PHENIX is consistent with $v_1\{3\}$ from STAR experiments.
- The results of $v_1\{RP_2\}$ and $v_1\{3\}$ indicate that v_2 @ RHIC is *in-plane* ($v_2 > 0$).

Outlook



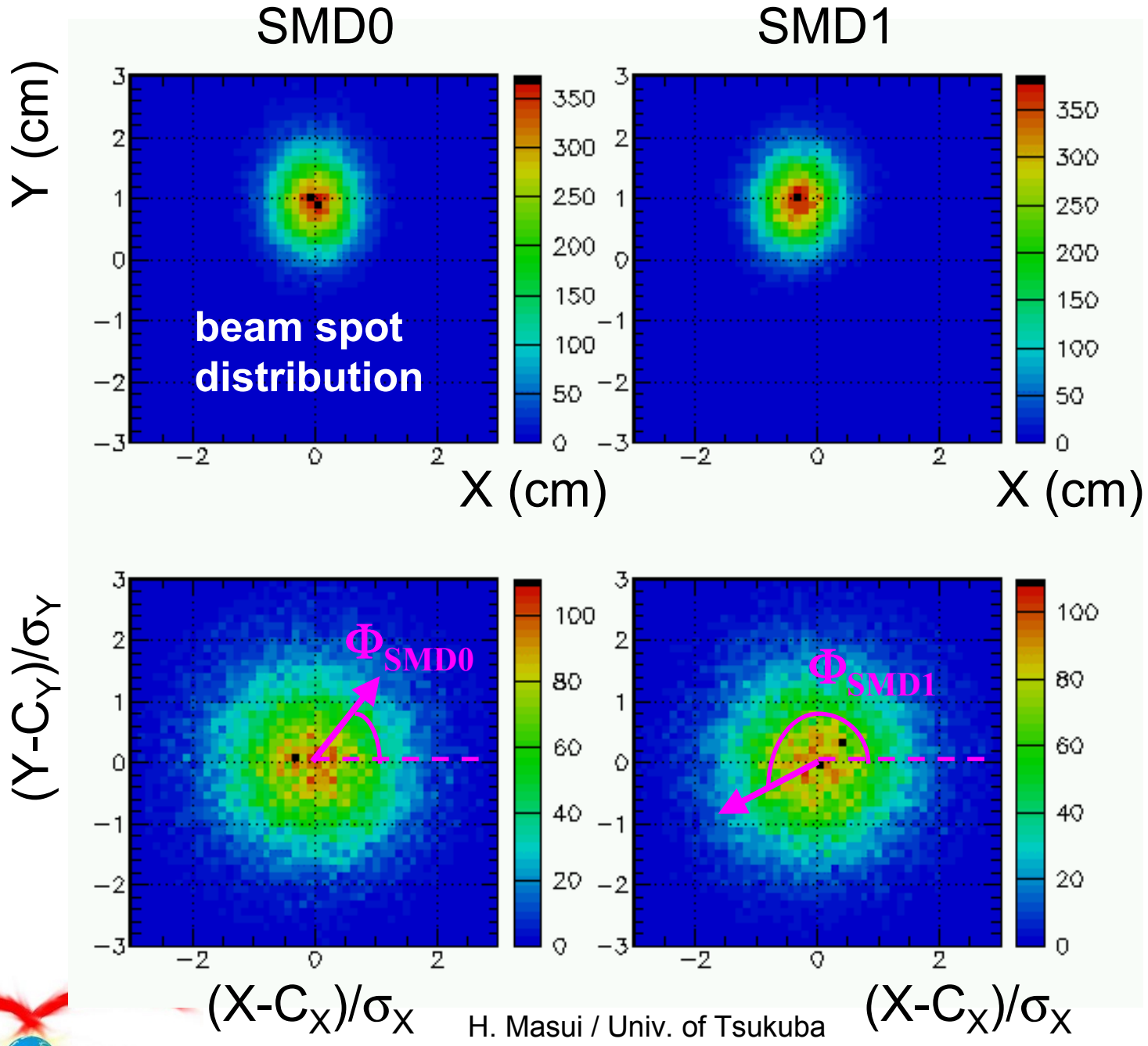
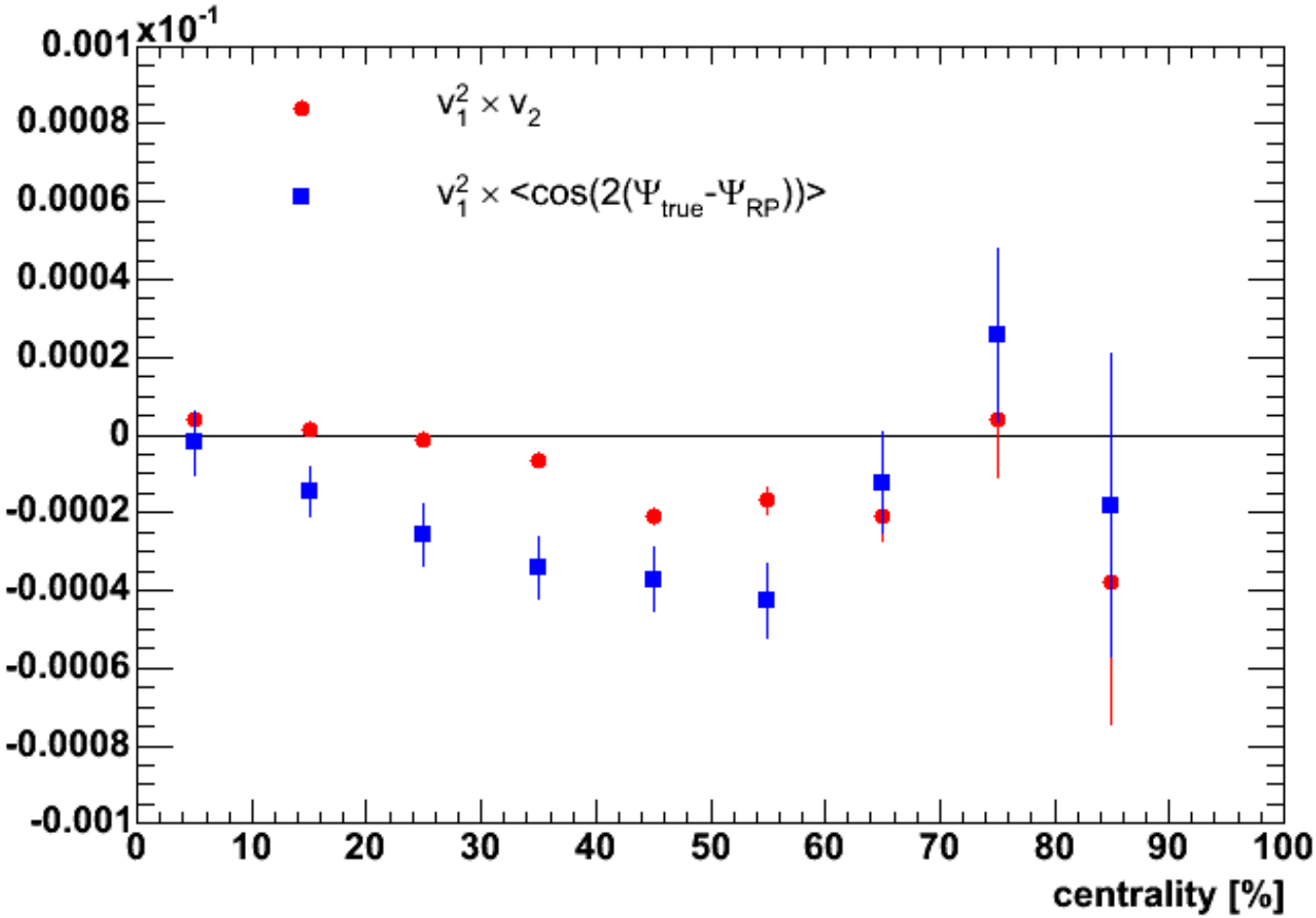
Shower Maximum Detector (SMD)





- Directed event plane determined @ SMD
  - Better resolution.
  - Less sensitive to non-flow contribution.
  - Opposite direction between BBC and SMD ↔ Directed Flow from Participant (pion) and Spectator (neutron).

Back up


SMD0
SMD1
Y (cm)
beam spot distribution
X (cm)
X (cm)
$(Y-C_Y)/\sigma_Y$
Φ_{SMD0}
Φ_{SMD1}
$(X-C_X)/\sigma_X$
$(X-C_X)/\sigma_X$

In-plane Elliptic Flow